THE ASTROPHYSICAL JOURNAL, 423:L125–L126, 1994 March 10

AN OPTICAL COUNTERPART FOR PSR 1509−58[1]

P. A. CARAVEO, S. MEREGHETTI, AND G. F. BIGNAMI[2]
Istituto di Fisica Cosmica del CNR, via Bassini 15, 20133 Milano, Italy
Received 1992 October 7; accepted 1993 December 16

ABSTRACT

We propose a candidate for the optical identification of PSR 1509−58. This is the second youngest pulsar, with the highest recorded $\dot{P}$ and a period of 150 ms. Its subarcsecond radio position is seen to coincide accurately with a 22 mag object observed from the European Southern Observatory with the New Technology Telescope. At the reported distance of PSR 1509−58, the optical luminosity of the candidate ($\sim 5 \times 10^{32}$ ergs s^{-1}) rules out thermal emission from the neutron star surface. Its luminosity value is comparable to that of the Crab and PSR 0540−69 pulsars and as such is much higher than previous predictions. However, the efficiency of transforming rotational energy loss into nonthermal optical light for PSR 1509−58 is seen to follow a $\dot{P}$ dependence already outlined by the optical emission from the Vela, Crab, and PSR 0540−69 pulsars.

Subject headings: pulsars: general — pulsars: individual (PSR 1509−58)

1. INTRODUCTION

Optical emission from isolated neutron stars has recently become of interest with the confirmation of the Geminga optical counterpart (Bignami et al. 1993) and the finding of a probable candidate for PSR 0656+14 (Caraveo, Bignami, & Mereghetti 1994). These join the existing results for the Crab and Vela pulsars, as well as the more recent identification of PSR 0540−69 (Middleditch & Pennypacker 1985; Caraveo et al. 1992; Shearer et al. 1993) in the Large Magellanic Cloud. From a global look at the optical data existing so far, Caraveo et al. (1994) noted the important role played by the neutron star age and/or by its period derivative. It was then natural to make a prediction for substantial optical emission from young, high-$\dot{P}$ objects, starting with PSR 1509−58.

PSR 1509−58 is the isolated neutron star with the highest period derivative (1.5×10^{-12} s s^{-1}). Thus, its characteristic age ($\tau = P/2\dot{P}$) is similar to that of the Crab pulsar, in spite of its period being 5 times longer. It was discovered through its X-ray emission (Seward & Harnden 1982) and observed to emit up to soft γ-ray energies (Wilson et al. 1992; Ulmer et al. 1993; Laurent et al. 1993). The only available optical counterpart search so far is a report (Seward et al. 1983) of a couple of marginally visible objects in the X-ray error box. A more accurate, subarcsecond radio position was obtained a few years later (Manchester, Durdin, & Newton, 1985), but with no optical follow-up.

2. THE OBSERVATIONS

On the nights of 1993 June 22–23 we performed deep imaging of the PSR 1509−58 field with the ESO NTT, remotely controlled. Specifically, several images were taken with the ESO Multi Mode Instrument, using a CCD with a pixel size of 0″.35, through the standard *R*, *V*, *B* filters. The seeing was good (∼1″.0), but the nights were not photometric, due to the variable presence of thin cirrus. Figure 1 (Plate L23) shows a 3 minute *V*-filter image of the field. Astrometry was performed using several *Hubble Space Telescope* Guide Star Catalogue stars, located on the same EMMI plate. The accuracy of our final astrometric solution is certainly better than one image pixel. Our object, indicated by an arrow, is located at $\alpha_{(J2000)} = 15^h13^m55^s.52$, $\delta_{(J2000)} = -59°8'8''.8$, with an error of $\pm 0''.5$, also including centering uncertainties.

The most recent radio position of PSR 1509−58 as given in Taylor, Manchester, & Lyne (1993) is $\alpha_{(J2000)} = 15^h13^m55^s.58 \pm 0^s.05$, $\delta_{(J2000)} = -59°8'8''.7 \pm 0''.7$. In view of the positional coincidence, we suggest this object as the optical counterpart of PSR 1509−58. Within the limits of the photon statistics, its profile is consistent with that of a single point source with no detectable sign of spatial extension. It has $m_v = 22.0 \pm 0.2$, $m_r = 20.8 \pm 0.3$, $m_b > 23$. It is probably the western one of the two objects barely visible in Figure 6*b* of Seward et al. and mentioned by them. At the reported distance (∼4.4 kpc) and low Galactic latitude of PSR 1509−58, the heavy interstellar absorption ($A_v \gtrsim 4$) makes it not surprising that we could not obtain a convincing detection in *B*. The $V-R$ color of our candidate (+1.2), unfortunately, does not help in assessing the nature of the object: a flat continuum, like, for example, that of the Crab pulsar, through heavy reddening, or a slightly less reddened field star could give the same color index as above.

3. DISCUSSION

If our candidate is indeed the optical counterpart of PSR 1509−58, some interesting consequences follow. First, it is apparent that, at the reported distance and reddening, the inferred (*V*-band) luminosity of $\sim 5 \times 10^{32}$ ergs s^{-1} is too bright, by many orders of magnitude, to be the thermal emission from the surface of a neutron star at any reasonable temperature for its age. PSR 1509−58 would thus join PSR 0540−69, the Crab, and Vela pulsars in a very restricted group of pulsars for which there is firm evidence of nonthermal optical emission. Table 1 lists the key parameters of these four pulsars, ordered as a function of $\dot{P}$. For each object we also give the time-averaged optical luminosity and efficiency, the latter defined as the *V*-band optical luminosity expressed in units of the neutron star's rotational energy loss, $\dot{E}$. Two more isolated neutron stars have been detected at optical wavelengths, that is, PSR 0656+14 (Caraveo et al. 1994) and Geminga (Bignami, Caraveo, & Mereghetti 1993 and refer-

[1] Based on observations collected at the European Southern Observatory, La Silla, Chile.

[2] Dipartimento Ingegneria Industriale, Università di Cassino.

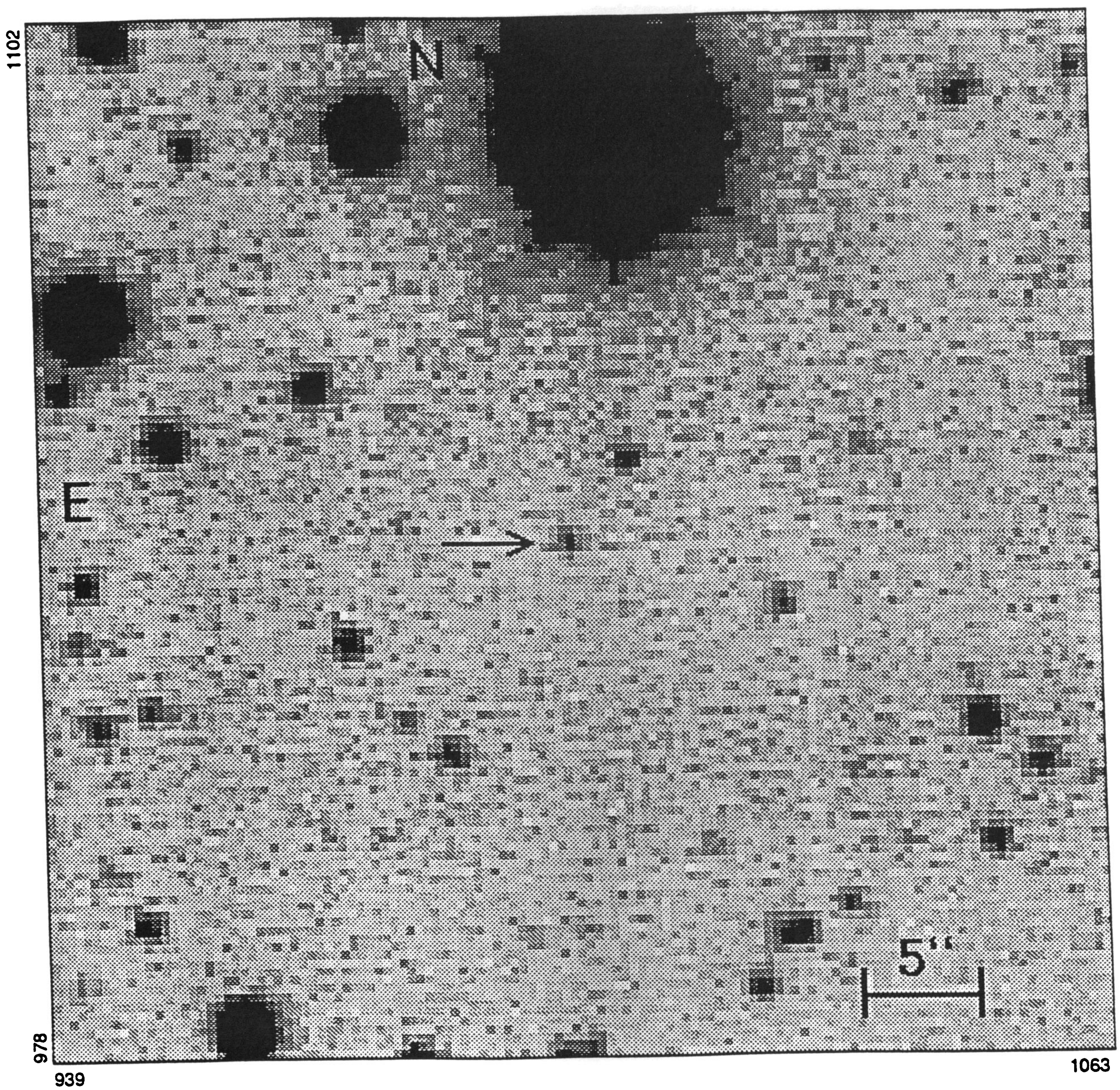

FIG. 1.—Field of PSR 1509−58, taken with the ESO NTT (3 minute *V*-band exposure). The 22 mag optical candidate counterpart for the pulsar is shown by the arrow. The subarcsecond radio position is inside the star's image, within less than 2 pixels of its centroid (1 pixel = 0".35).

CARAVEO, MEREGHETTI, & BIGNAMI (see 423, L125)

TABLE 1

ISOLATED NEUTRON STARS WITH NONTHERMAL OPTICAL EMISSION

Pulsar	P (s)	$\dot{P}$ (10^{-15}) (s s^{-1})	$\dot{E}$ (ergs s^{-1})	τ (yr)	d (kpc)	Average V Magnitude	L_V (ergs s^{-1})	Efficiency
1509−58	0.1502	1540	1.8×10^{37}	1545	4.4	$22.0_{(A_V \sim 4)}$	4.7×10^{32}	2.6×10^{-5}
0540−69	0.0504	479	1.48×10^{38}	1670	49.4	$22.4_{(A_V = 0.6)}$	1.8×10^{33}	1.2×10^{-5}
0531+21	0.0334	420	4.46×10^{38}	1260	2.0	$16.6_{(A_V = 1.6)}$	1.5×10^{33}	3×10^{-6}
0833−45	0.0893	124	6.9×10^{36}	11350	0.5	$23.6_{(A_V = 0.4)}$	5.0×10^{28}	7.2×10^{-9}

ences therein). However, for both, thermal emission cannot be ruled out, so they are not included in the table. All six objects are also pulsating X-ray sources, and their multiwavelength behavior is thoroughly discussed in Mereghetti, Caraveo, & Bignami 1994). In any event, in the rather wide energy band from 2 keV to hundreds of keV, the nonthermal nature of the electromagnetic emission from PSR 1509−58 appears firmly established (Wilson et al. 1992; Ulmer et al. 1993; Laurent et al. 1993).

As a second consequence, were its optical luminosity to scale with the B^4P^{-10} law (Pacini 1971), our object would be a factor of 6×10^4 fainter than the Crab. If our identification is correct, this is clearly not the case. Moreover, such a large discrepancy could not be accounted for by any correction for duty cycle (yet to be measured in the optical), as invoked successfully (Pacini & Salvati 1987) to explain the difference of ~ 20 between the observed and predicted PSR 0540−69 optical powers.

Furthermore, we note that a simple extrapolation to optical wavelengths of the flat power-law spectrum measured at X-ray energies (Trussoni et al. 1990; Wilson et al. 1992) falls between one and two orders of magnitude below the dereddened optical flux. The implied change of slope in the object's overall spectrum yields a higher optical to X-ray power ratio than observed for the Crab and PSR 0540−69.

We propose that the high optical luminosity of PSR 1509−58 (should the present optical identification be confirmed) be linked to its very high value of $\dot{P}$. As an illustration, it is interesting to plot the pulsars' optical "efficiency" as a function of $\dot{P}$. Figure 2 shows such a plot for the nonthermal optical emitters listed in Table 1. The present candidate for PSR 1509−58 appears to follow the monotonic trend defined by the other three nonthermal optical identifications. Finally, we note that our unresolved candidate does not show signs of an optical synchrotron nebula around it, in spite of reported evidence for such a nebula in X-rays (Seward et al. 1983). Of course, a small (fraction of pc) unresolved nebula contributing to the visible light cannot be ruled out.

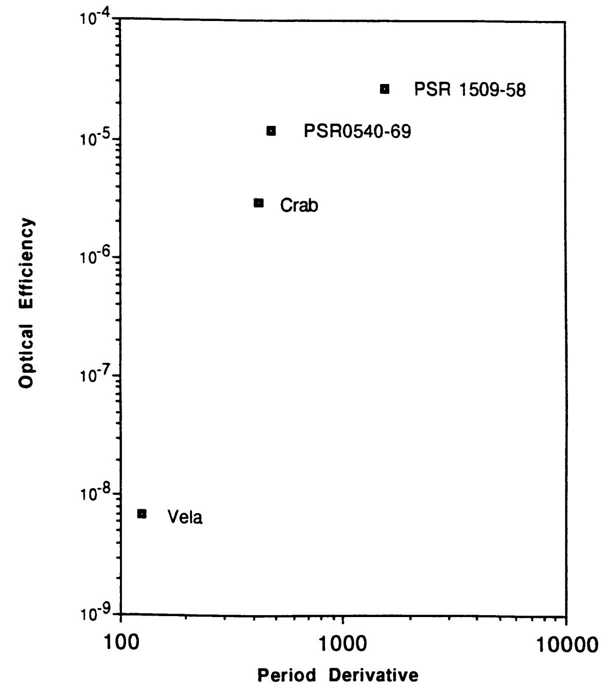

FIG. 2.—Optical efficiency vs. $\dot{P}$ (in units of 10^{-15} s s^{-1}) for the four pulsars emitting nonthermal optical radiation. The optical efficiency is defined as the object's optical power in units of the total star's spin-down energy loss $\dot{E} = I\Omega\dot{\Omega}$.

The next step is, obviously, to perform periodicity analysis on the optical light of the candidate reported here. This will confirm our proposed identification and provide important comparison to the X-ray/radio phase diagram, leading to a new pulsar for which multiwavelength data become available.

REFERENCES

Bignami, G. F., Caraveo P. A., & Mereghetti, S. 1993, Nature, 261, 704
Caraveo, P. A., Bignami, G. F., Mereghetti, S., & Mombelli, M. 1992, ApJ, 395, L103
Caraveo, P. A., Bignami, G. F., & Mereghetti, S. 1994, ApJ, 422, L87
Laurent, P., et al. 1993, A&A, submitted
Manchester, R. N., Durdin, J. M., & Newton, L. M. 1985, Nature, 313, 374
Mereghetti, S., Caraveo, P. A., & Bignami, G. F. 1994, ApJS, 92, in press
Middleditch, J., & Pennypacker, C. 1985, Nature, 313, 659
Pacini, F. 1971, ApJ, 163, L17
Pacini, F., & Salvati, M. 1987, ApJ, 321, 447
Seward, F. D., & Harnden, F. R. 1982, ApJ, 253, L45
Seward, F. D., et al. 1983, ApJ, 267, 698
Shearer, A., et al. 1993, IAU Circ. 5786
Taylor, J. H., Manchester, R. N., & Lyne, A. G. 1993, ApJS, 88, 529
Trussoni, E., et al. 1990, A&A, 234, 403
Ulmer, M. P., et al. 1993, ApJ, 417, 738
Wilson, R. B., et al. 1992, in Proc. Isolated Pulsar Workshop, ed. K. A. van Ripper, R. Epstein, & C. Ho (Cambridge: Cambridge Univ. Press), 257